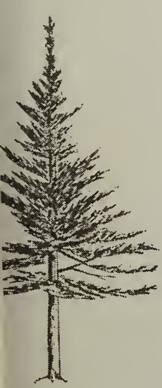
Average Growth Rates in the Spruce-Fir Region of New England



by
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STATION PAPER NO. 140 • NORTHEASTERN FOREST EXPERIMENT STATION • 1961
FOREST SERVICE • U.S. DEPARTMENT OF AGRICULTURE • UPPER DARBY, PA.
RALPH W. MARQUIS, DIRECTOR

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Introduction

THE fact that trees grow makes the extraction of logs and bolts from a forest different from the extraction of ore from a mine. Every mine has a limit, and sooner or later it must be abandoned, either because the vein has run out or because the mine has become too costly to operate. But a properly managed forest--one where cutting maintains production--never becomes exhausted by harvesting operations alone.

Trees grow by adding successive layers of wood. This means that the annual growth of wood cannot be harvested like corn or potatoes. Instead, the forest manager relates

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[1] Data for this study were obtained from plots established and remeasured by the following timberland owners: Brown Co., Dead River Co., Great Northern Paper Co., International Paper Co., Penobscot Development Co., St. Regis Paper Co., Scott Paper Co., Standard Packaging Corp. (Eastern Corp.), James W. Sewall Co., and S. D. Warren Co. These are the concerns cooperating in the growth study for the spruce-fir region of Maine and adjoining New Hampshire.

the volume removed by cutting to the volume added by growth. On the average, with a properly balanced forest, cutting should equal growth.

The forests of the Northeast are generally understocked, so that growth should exceed the cut while the stands are being built up to what is desired. Thus, a knowledge of growth is extremely important to the forest manager.

NEED FOR GROWTH DATA

The manufacture of paper from wood became important in northern New England around the turn of the century. And for thirty years or more the supply of wood was more than adequate for this industry's needs; technology made more and more species available for paper making, and water transport became less essential. Then, during and immediately after World War II, wood procurement became difficult because of limited supplies of wood, as well as shortages of manpower and equipment. Although officials of most companies were concerned with the increasing scarcity of suitable wood, some believed they already owned too much wild land. The answer in either case required more exact information on the growth of their forests than was available in the late 1940's. For many years growth estimates were made by rule of thumb--"one- to two-tenths cords per acre per year." But foresters now feel that this formula is no longer valid, if it ever was.

In this area of New England, wood-using industries exert a profound effect upon employment and wages and upon the dependent services. Approximately one-third of the people in Maine[2] work in the forests or in wood-using industries. They produce nearly two-fifths of all the state's products in value. Thus, to the extent that such industries might be compelled to shut down or move, or that they might grow and expand, the people too have an interest in more accurate information about the growth of these forests.

GROWTH DEFINED

At this point perhaps we should consider what is meant by growth--that is, growth in relation to the management of a forest. It is a subject that is not always well understood. Increment might be a better word than growth,

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[2]Census of Maine manufacturers. Maine Dept. of Labor and Industry Rpt. 262, 40 pp. (mimeo), 1957.

but it never caught on for general usage. If trees on the same area are measured on two successive occasions, net growth in volume is the difference in volume between these two measurements.

This brings out the importance of care and consistency in the basic measurements. If trees are measured on two successive occasions, their difference in diameter, height, or volume is growth. Thus to minimize measurement errors, trees should be measured in the same manner, at the same place, with the same definitions. Furthermore, to avoid bias in estimating volume growth, the same volume table must be used at each occasion, adjusting for changes in height and form as may be necessary.

To better appreciate the make-up of net growth, consider the changes that may occur in the interval between measurements: some trees die; others may be cut; the remainder increase in size. Some trees of this remainder become useless because of increased rot or other defect. Others may grow to merchantable size. For the sound trees that increase in size, volume added to trees previously measured is *accretion* while the entire volume of trees that cross the threshold of measurement is *ingrowth*. The volume of trees that die is *mortality*.

Accretion also includes volume added to trees that die or are cut during the interval. Ingrowth would include any trees that grew into measurable size and died during the interval and any trees previously considered cull that become merchantable. Mortality may include volume of some trees not previously measured and does include volume added to trees initially measured that die during the interval. Trees that become cull are effectively the same as mortality even though still alive.

These three--accretion, ingrowth, and mortality--are the elements of net growth as defined above:

Net growth is accretion plus ingrowth minus mortality.

Gross growth is net growth plus mortality, or accretion plus ingrowth.

Factors that affect net growth are those that affect the growth and survival of trees. Some of these more important factors are species, site, density, climate, age, and associated vegetation. It is evident that many of these are difficult to identify and measure. Factors affecting

growth are often so interrelated that a broad classification such as forest type will include, to some degree, species, site, climate, and associated vegetation.

COOPERATIVE GROWTH STUDY PLANNED

In the mid and late 1940's concern over the continued availability of wood for paper in sufficient volume deepened. And this concern brought about increased interest in more dependable growth data for the spruce-fir area, especially in Maine and northern New Hampshire. The cooperative growth study was organized to provide these needed data; the work was largely a result of the interest and efforts of a few company foresters. The working plan[3] which has guided the project was written and approved in 1950. Field work was begun that same year and the last plots were established in 1955.

Purpose of This Report

More than three-fourths of the plots had been remeasured once by the end of 1958 and, in response to mounting interest and an insistent demand, Longwood reported preliminary results at the New England Section meeting of the Society of American Foresters in March 1959. This paper has been prepared to make those preliminary results more readily available and to supplement them with analyses made since the meeting.

This report is preliminary--the calculated statistics do not include data from more than 200 of the established plots. However, these additional plots will probably not materially affect the means and variances that have been calculated if they are from the same population, as has been assumed. The report that is planned when all plots have been remeasured once is expected to differ principally in that a more thorough analysis will be made. It may be expected by 1962; it will seek to establish basic relationships and to identify influencing factors as well as to revise means and variances as may be needed.

[3]Working plan for joint cooperative growth study for spruce-fir region of Maine. Northeast. Forest Expt. Sta. and Maine Timberland Owners. 1950.

The Study Is Established

As soon as the plan was approved by the eight original cooperators,[4] plot establishment was begun. The plan included a detailed description of the standard field procedure for plot selection, establishment, and remeasurement. The companies established and remeasured the plots while the Northeastern Forest Experiment Station served as coordinator, compiling and analyzing the data.

The general purpose of the study was to learn the average growth rates so that the cooperating companies could more accurately estimate the growth of spruce and fir on their holdings. The allowable error was set at 10 percent of the mean for the spruce-fir component. It was recognized that growth would vary by forest type and might also be affected by density and height of the dominant stand. The influence of other factors was also considered, but there seemed to be no practical way to include them for all cooperators. Variation in these three factors--density, height, and type of stand--would define strata, or classes, of forest land and were expected to be more efficient criteria than other factors for sampling periodic growth. Data from all cooperating companies was pooled to provide stronger averages by classes. This procedure presumes that averages by classes are the same for all companies.

SAMPLING DESIGN

Classes used in this study were adapted from Spurr[5] because five of the original cooperators had used similar classes in their forest inventories based on aerial photographs. The other cooperating companies would be able to estimate areas by these classes and so obtain the needed strata weights. The classes finally adopted were a compromise among those cooperators having air photo coverage of their lands. Twenty-seven classes were defined recognizing three levels in each of three factors: forest type, stand density, and stand height. These levels are as follows:

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[4]The first seven companies previously listed in Footnote 1, plus the Northeastern Forest Experiment Station; the other three came in soon thereafter.

[5]Spurr, S. H. Aerial photographs in forestry. 340 pp. New York, 1948.

Forest Type

(S) Softwood	66 - 100	percent softwood species
(M) Mixedwood	21 - 65	percent softwood species
(H) Hardwood	0 - 20	percent softwood species

Stand Height

(1) Less than 35 feet
(2) 35 - 64 feet
(3) More than 64 feet

Stand Density

(A)	71 - 100	percent crown closure
(B)	41 - 70	percent crown closure
(C)	11 - 40	percent crown closure

Thus, three symbols would identify a particular class: S1A for example, would stand for softwoods less than 35 feet in stand height and with a 71-100 percent stand density.

Aerial Photographs Used

Where aerial photos were available, these classes were to be identified on the photographs. However, to include in the study as many companies as would like to cooperate, it was agreed that possession of aerial photographs, though desirable, was not a requisite. The sampling design was planned on the basis of such photographs and those without them recognized that it might not be possible to pool their data with those who had photographs.

Another problem arose: the possibility of differences in photo interpretation among the companies. It was proposed to solve this question by having an experienced forest survey interpreter[6] classify all plots with photos. A subsequent analysis would determine whether or not there were real differences and how to adjust if necessary. This analysis will be made when all plots have been remeasured once.

Number and Distribution of Plots

Desired accuracy is essential in specifying the number of plots to remeasure. As has been noted, the allowable error was set at 10 percent of the mean for the spruce-fir

[6] T. J. Grisez served as photo interpreter. His work is gratefully acknowledged.

component. In estimating sample size, this standard of precision was interpreted to apply to the weighted average of all classes. Areas from forest survey data for northern New Hampshire and variances estimated from available data from remeasured plots were used in calculating the number of sample plots required. (Areas will sometimes vary from one property to another and ten percent accuracy may not be met in all cases.) The number of plots so estimated was 860; Their distribution by classes is shown in table 1. These plots were then distributed by cooperators in July 1950 without regard to stand classes (see table 2).

Table 1.--Numbers of plots (by classes) estimated to be needed

Height class	Forest type (stand density in percent)								
	Softwoods			Mixed woods			Hardwoods		
	11-40	41-70	70+	11-40	41-70	70+	11-40	41-70	70+
0-34(1)	40	50	40	20	50	30	10	20	10
35-64(2)	50	60	50	20	60	40	10	20	10
65+(3)	50	60	50	20	30	20	10	20	10

FIELD PROCEDURE

Where aerial photographs were available, plots were established at random within the appropriate delineated class. In the absence of photographs, plots were selected at random from permanent cruise plots after they were classified on the basis of type, height, and density. No attempt was made to assign numbers of plots by classes to a company. Instead, at the close of each field season (until plot establishment was considered complete), numbers that had been established were reported to all cooperators. In the following season each company tried to take plots from table 1 where the need was greatest. As a result more plots were established in the common classes than had been estimated to be necessary and not enough plots were established in the large and small height classes and in the low density classes. A total of 1,122 plots were so established, of which 865 have been remeasured. It is the data from the 865 remeasured plots that has been used in this report.

In remeasuring these plots, the usual difficulties were encountered. Errors of omission and duplication may

occur in each tally and there are of course the common mistakes made in reading scales, identifying species, and recording data. For these reasons, it was not always possible to achieve perfect agreement between successive tallies of the same plot, even with due allowance for growth. The significant point is not that such mistakes were made but that for this study the proportion of affected plots was as small as it was. This is an inescapable problem in remeasuring plots; and it is why such extreme care must be taken in these measurements. Though it is a weakness of growth estimates based on remeasured plots, it is still trivial in comparison with available alternatives.

Table 2.--Number of plots, by cooperators

Cooperator	Allotted	Established	Remeasured (to 1-1-59)
Brown	90	78	78
Dead River	60	228	185
Great Northern	350	357	342
International	90	94	0
Penobscot	90	120	119
St. Regis	90	78	22
Scott	90	110	87
S. D. Warren	0	18	0
James W. Sewall	40	25	23
Standard Packaging (Eastern Corp.)	0	14	9
Total	900	1,122	865

Table 3.--Numbers of remeasured plots by classes

Height class	Forest type (stand density in percent)								
	Softwoods			Mixed woods			Hardwoods		
	11-40	41-70	70+	11-40	41-70	70+	11-40	41-70	70+
0-34(1)	4	13	41	8	3	5	0	2	2
35-64(2)	34	166	164	28	189	66	60	34	20
65+(3)	0	0	4	0	2	6	2	6	6

Results from the remeasurement of these 865 plots were reported by Longwood at the Boston S.A.F. meeting in March 1959. Class distribution of the plots is shown in table 3.

ANALYSIS OF DATA

Volume Computations

The basic data consisted of tallies of trees by species and by d.b.h. for each of the 865 plots, both at establishment and remeasurement. These data were converted to volume in cubic feet, using Austin Cary's tables[7], as follows: spruce from Cary's table 6 was reduced by 12½ percent to give wood-without-bark; other softwoods were reduced an additional 8 percent to reflect differences in form; and hardwoods were estimated from Cary's table described on pages 138 to 146 of the Report of the Forest Commissioner (Maine) for 1933-1934.

The volume data are shown in cubic feet of wood-without-bark; this is volume used that may be measured objectively and consistently. Selected results are converted to cords of rough and peeled wood using 80 and 96 cubic feet per cord, respectively. Of course, the cord is the standard industrial unit for buying and selling wood. But because of its looseness as a unit of measure--a fact well-known by anyone who has ever stacked wood--the basic computations are in cubic feet.

Results are shown by five different species groups: spruce-fir-hemlock, all softwoods, beech-birch-maple, all hardwoods, and all species. These groups were selected on the basis of industry's expected interest. Beech-birch-maple includes beech, yellow birch, sugar and red maple, but not paper (white) birch. Otherwise the group names are clear. More detailed information on the groups is planned for the next report.

Net new growth as used throughout this report is the difference in volume at two successive tallies.

Tests Made

The first question requiring analysis was whether there was need to separate those plots classified from aerial photographs from those classified only on the ground. This procedure was tested statistically using net growth of spruce-fir-hemlock. Differences between means by classes were small enough to have been random. Thus all the data were pooled, and the original 27 classes preserved in so far

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[7]Cary, Austin. Woodsman's manual. Fourth Ed., 323 pp. Harvard Univ. Press, Cambridge, 1932.

as they were represented (see table 3). And so cooperators without photographs were able to use results from all cooperators.

Even though this test failed to reveal a significant difference between the two sets of data, there is the possibility of a consistent difference in photo interpretation between Grisez and one or more of the company interpreters. If this were true, use of strata weights based on delineations by the company interpreter could result in a biased estimate of growth. This problem will be studied when all plots have been remeasured.

Next, the need for all 27 classes was challenged Analysis of variance of net growth in spruce-fir-hemlock was used and the "F-ratio" for classes proved highly significant. Component analysis supported the continued use of classes based on composition and height but indicated that the two lower density classes, B (41-70 percent) and C (11-40 percent), could be combined. These data were accordingly pooled, resulting in 18 possible classes with data for 17 as shown in tables 4 and 5. (It is recognized that other species groups or net growth of all species might give different results; appropriate tests will be made when all plots have been remeasured.)

Results and How to Use Them

Averages by classes were then computed, showing growth by components for the five species groups (see table 4). Initial volume, gross growth, and net growth are also given for all species. As will be brought out, this table is chiefly valuable for diagnosis. It could, of course, be used to estimate accretion of spruce-fir-hemlock, or any other similar combination. As a result of inadequate sampling, some of the entries in this table are obviously inconsistent. It is unlikely, for example, that there is really no growth of beech-birch-maple in class H1A (hardwood, 0-34 feet in height, 70-100 percent density), but the two plots in this class just happen not to have had any beech, birch, or maple trees on them. Nonetheless, the averages shown are the best estimates available.

Table 4.--Average annual growth in gross volume by components, species groups, and stand classes, in spruce-fir region of Maine and northern New Hampshire

(cubic feet per acre)

Stand class			Spruce-fir-hemlock			All softwoods		
			Accretion	Ingrowth	Mortality*	Accretion	Ingrowth	Mortality*
Softwoods	0-34	70+	22.8	29.0	3.3	27.0	30.4	4.7
	35-64	70+	47.7	21.1	10.2	52.8	22.1	13.8
	65+	70+	56.5	5.6	28.9	58.6	6.8	38.4
Softwoods	0-34	11-70	21.9	23.9	3.4	26.1	23.9	3.4
	35-64	11-70	43.1	20.5	12.3	50.0	21.4	18.3
	65+	11-70	--	--	--	--	--	--
Mixed woods	0-34	70+	28.8	16.1	.0	30.9	16.1	0.7
	35-64	70+	38.3	18.8	12.2	40.4	19.3	12.3
	65+	70+	17.3	4.6	17.9	17.7	4.9	17.9
Mixed woods	0-34	11-70	12.7	12.5	.6	12.7	12.5	0.6
	35-64	11-70	32.9	13.5	10.0	35.9	14.2	11.6
	65+	11-70	30.4	11.5	1.2	30.4	11.5	14.4
Hardwoods	0-34	70+	6.7	.0	.0	8.7	.0	0.0
	35-64	70+	8.8	3.3	4.7	8.8	3.5	4.7
	65+	70+	11.0	1.9	9.3	11.0	1.9	9.3
Hardwoods	0-34	11-70	.0	.0	.0	.0	.0	.0
	35-64	11-70	10.7	5.2	2.8	10.9	5.2	2.9
	65+	11-70	8.3	2.7	.4	8.6	2.7	0.4

(continued)

Table 4.--continued.

Stand class			Beech-birch-maple			All hardwoods		
			Accretion	Ingrowth	Mortality*	Accretion	Ingrowth	Mortality*
Softwoods	0-34	70+	0.5	0.1	0.0	0.5	0.2	0.2
	35-64	70+	2.4	1.4	3.7	3.7	1.8	4.8
	65+	70+	2.3	3.8	.0	2.3	3.8	
Softwoods	0-34	11-70	.4	.5	4.2	1.1	1.9	4.6
	35-64	11-70	2.2	1.6	4.8	3.6	2.3	6.1
	65+	11-70	--	--	--	--	--	--
Mixed woods	0-34	70+	.0	.0	.0	2.9	.0	1.3
	35-64	70+	7.6	2.9	9.0	9.9	4.2	11.2
	65+	70+	3.5	1.5	40.5	3.5	1.5	40.5
Mixed woods	0-34	11-70	3.2	4.9	1.1	4.9	10.8	3.7
	35-64	11-70	8.7	4.5	10.3	10.2	5.3	12.4
	65+	11-70	14.4	6.7	5.2	14.4	6.7	5.2
Hardwoods	0-34	70+	.0	.0	.0	4.5	16.1	.0
	35-64	70+	7.4	8.0	11.4	13.8	15.8	17.4
	65+	70+	14.2	3.6	9.7	14.9	5.1	9.7
Hardwoods	0.34	11-70	21.7	9.0	11.1	21.7	14.3	11.1
	35-64	11-70	17.4	6.2	15.3	18.7	6.9	16.6
	65+	11-70	16.9	9.2	34.4	16.9	9.2	34.4

(continued)

Table 4.--continued.

Stand class			All species					
			Initial volume	Accretion	Ingrowth	Mortality*	Gross growth	Net growth
Softwoods	0-34	70+	849	27.5	30.6	4.9	58.1	53.2
	35-64	70+	1,858	56.5	23.9	18.6	80.4	61.8
	65+	70+	1,966	60.9	10.6	38.4	71.5	33.1
Softwoods	0-34	11-70	430	27.2	25.8	8.0	53.0	45.0
	35-64	11-70	1,559	53.6	23.7	24.4	77.3	52.9
	65+	11-70	--	--	--	--	--	--
Mixed woods	0-34	70+	947	33.8	16.1	2.0	49.9	47.9
	35-64	70+	1,698	50.3	23.5	23.5	73.8	50.3
	65+	70+	2,496	21.2	6.4	58.4	27.6	30.8
Mixed woods	0-34	11-70	273	17.6	23.3	4.3	40.9	36.6
	35-64	11-70	1,428	46.1	19.5	24.0	65.6	41.6
	65+	11-70	1,910	44.8	18.2	19.6	63.0	43.4
Hardwoods	0-34	70+	247	13.2	16.1	.0	29.3	29.3
	35-64	70+	896	22.6	19.3	22.1	41.9	19.8
	65+	70+	2,132	25.9	7.0	19.0	32.9	13.9
Hardwoods	0-34	11-70	492	21.7	14.3	11.1	36.9	24.9
	35-64	11-70	903	29.6	12.1	19.5	41.7	22.2
	65+	11-70	1,308	25.5	11.9	34.8	37.4	2.6

*Mortality includes volume of trees that became cull and a few trees that were cut without explanation.

NET GROWTH & ITS COMPONENTS

The practical forest manager, however, is more concerned with net growth, even though study of the above components may be interesting to him. Data on net growth together with the corresponding variances and numbers of plots are shown in table 5. These data provide the basis for estimating total or mean growth for a specific area of forest land.

HOW TO USE THESE GROWTH DATA

We now come to the matter of how these growth data will be used in specific situations, particularly by the large landowner. Let's consider two examples.

In the first place, suppose it is desired to estimate growth for a particular property. In addition to the data in table 5, it is necessary to know area for each of the classes represented. Growth for the property is then estimated by the sum of products of area and average net growth. A numerical example is shown in table 6, where areas were assumed.

EXAMPLE 1: On an *assumed* forest of 51,350 acres in northern Maine, aerial photographs were delineated to obtain areas by stand classes.

The calculations necessary to estimate net growth of spruce-fir-hemlock for this property are shown in table 6. Area data were derived from the assumed photo delineations. Average growth rates were read from table 5. The products of area and growth are shown in the next to last column. The sum of these products is estimated annual net growth for the whole property expressed as cubic feet of wood-without-bark. The same result could have been obtained by calculating the proportions of area, as shown in the third column of table 6. The sum of the products of these proportions with average growth by classes is average growth per acre for the entire area, 44.8 cubic feet in this example. And multiplying this average by total area gives the same annual net growth for the whole property, except for errors due to rounding off. For this purpose alone there is no particular advantage. For calculating sampling errors, however, these proportions are needed and it becomes more efficient to use them than use the possibly more familiar procedure.

EXAMPLE 2: *Assume* that the 865 plots that have been remeasured are in fact a simple random sample of the spruce-fir

region of Maine and northern New Hampshire and that the area of this region is *assumed* to be fifteen million acres.

The necessary calculations are shown in table 7, columns 1, 2, 3, 4, and 6. Numbers of plots of column 2 were read from table 3. Average growth rates of column 3 were read from table 5. Proportions of column 4 were calculated from numbers of plots of column 2. Thus the average annual net growth of all species in the region is estimated to be 45.53 cubic feet per acre. For the region as a whole annual growth is estimated by multiplying this average by the area of the region, (*assumed* to be fifteen million acres), in this case, 682.95 million cubic feet is the estimated annual growth in this theoretical example.

These calculations have been made in cubic feet, which is measurable for the trees and plots of this study. The foregoing results may be expressed in cords by dividing by the proper number of cubic feet of wood per cord. The results tabulated below were obtained by using 80 cubic feet for a cord of rough wood and 96 cubic feet for a cord of peeled wood:

	Rough cords	*Peeled cords*
EXAMPLE 1		
Average per acre	0.56	0.47
Total for the property	28,743	23,953
EXAMPLE 2		
Average per acre	0.569	0.474
Total for the region	8,536,900	7,114,000

THE ASSOCIATED SAMPLING ERRORS

This cooperative study was undertaken to obtain average growth rates so that cooperators could estimate growth with a sampling error no larger than ten percent of the mean. The method of calculation is first described and this is followed by a brief discussion of what the sampling error means to the user of these data.

Method of Calculation

This study has been set up on the basis of stratified sampling so that adjustments can be made for growth differences due to species composition, stand height, and stand

Table 5.--Average net growth per year in gross volume and associated variances by species group and stand class

Stand class			Net growth					Plots	Variance[1]				
Species groups	Height	Density	Spruce fir hemlock	All softwoods	Beech birch maple	All hardwoods	All species		Spruce fir hemlock	All softwoods	Beech birch maple	All hardwoods	All species
	Feet	Percent	Cubic feet					Number					
Softwoods	0-34	70+	48.4	52.7	0.6	0.5	53.2	41	787	786	3	6	787
	35-64	70+	58.6	61.1	.1	.7	61.8	164	922	1,201	165	193	1,384
	65+	70+	33.2	27.0	6.1	6.1	33.1	4	2,471	2,512	33	33	2,750
Softwoods	0-34	41-70 11-40	42.4	46.6	-3.3	-1.6	45.0	17	831	1,477	84	125	1,784
	35-64	41-70 11-40	51.3	53.1	-1.0	- .2	52.9	200	1,719	2,184	177	216	2,511
	65+	41-70 11-40	--	--	--	--	--	0	--	--	--	--	--
Mixed woods	0-34	70+	44.9	46.3	.0	1.6	47.9	5	1,680	1,705	0	22	1,951
	35-64	70+	44.9	47.4	1.5	2.9	50.3	66	1,106	1,151	394	519	1,775
	65+	70+	4.0	4.7	-35.5	-35.5	30.8	6	1,624	1,578	2,259	2,259	3,092
Mixed woods	0-34	41-70 11-40	24.6	24.6	7.0	12.0	36.6	11	369	369	92	240	88
	35-64	41-70 11-40	38.4	32.5	2.9	3.1	41.6	217	1,708	1,780	621	767	2,372
	65+	41-70 11-40	40.7	27.5	15.9	15.9	43.4	2	171	32	853	853	1,215
Hardwoods	0-34	70+	6.7	8.7	.0	20.6	29.3	2	1	16	0	302	180
	35-64	70+	7.4	7.6	4.0	12.2	19.8	20	311	310	572	901	1,006
	65+	70+	3.6	3.6	8.1	10.3	13.9	6	731	731	841	678	711
Hardwoods	0-34	41-70 11-40	.0	.0	19.6	24.9	24.9	2	0	0	882	493	493
	35-64	41-70 11-40	13.1	13.2	8.3	9.0	22.2	94	352	343	1,317	1,573	1,806
	65+	41-70 11-40	10.6	10.9	-8.3	-8.3	2.6	8	137	139	3,193	3,193	3,208

[1] Variance is a statistical measure of the variation from plot to plot in net growth of a class; it is the square of the standard deviation, which may be more familiar.

Table 6.--Estimation of total net growth of spruce-fir-hemlock

Stand class			Area		Average net growth	Total net growth	Variance of net growth
Species groups	Height	Density					
	Feet	Percent	Acres	Proportion of total	Cubic feet	Cubic feet	Cubic feet
Softwoods	0-34	70+	9,830	0.191	48.4	475,772	787
	35-64	70+	7,040	.137	58.6	412,544	922
	0-34	11-70	11,720	.228	42.4	496,928	831
	35-64	11-70	13,100	.255	51.3	672,030	1,719
Mixed woods	0-34	11-70	6,410	.125	24.6	157,686	369
	65+	11-70	1,570	.031	40.7	63,899	171
Hardwoods	35-64	11-70	1,110	.022	13.1	14,541	352
	65+	11-70	570	.011	10.6	6,042	137
Total		--	51,350	1.000	--	2,299,442	--

density. It is therefore necessary to recognize these same strata in calculating the sampling error. The formula used here is given by Cochran:[8]

$$S_{\bar{x}} = \sqrt{\sum \left(\frac{P_i^2 S_i^2}{n_i} \right)}$$

where P_i is proportion of area in a class, S_i^2 is variance of the class, and n_i is the number of plots used to obtain mean growth and variance of the class. $S_{\bar{x}}$ is actually the standard error of the mean, $\bar{X}$, and is used to estimate the sampling error.

For example 1, refer to table 6: multiply the square of proportion by variance; divide by numbers of plots from table 3; sum over all eight classes and obtain the square root of this sum. Using S1A (softwoods, 0-34, 70+) to illustrate: $\frac{\left[(0.191)^2 (787) \right]}{41} = 0.700257$ is the contribution for that class. The sampling error is then the square root of the sum of eight such numbers. In this example, it was calculated to be 2.125 + cubic feet. As indicated by the sym-

[8]Cochran, W. G. Sampling techniques (p. 69). 320 pp. New York, 1953.

Table 7.--Calculation of mean growth for all species and its sampling error

1			2	3	4	5	6	7	8	9
Stand class			Plots	Area		Variance	Proportion times average growth	Column 4 times Column 5	Column 4 times Column 7	Column 8 divided by Column 2
Species groups	Height	Density								
	Feet	Percent	Number	Acres	Proportion of total		Cubic feet			
Softwoods	0-34	11-70	17	45.0	0.020	1,784	0.900	35.680	0.714	0.041976
	35-64	11-70	200	52.9	.231	2,511	12.220	580.041	133.989	.669947
Softwoods	0-34	70+	41	53.2	.047	787	2.500	36.989	1.738	.042402
	35-64	70+	164	61.8	.190	1,384	11.742	262.960	49.962	.304649
	65+	70+	4	33.1	.005	2,750	.166	13.750	.069	.017188
Mixed woods	0-34	11-70	11	36.6	.013	88	.476	1.144	.015	.001352
	35-64	11-70	217	41.6	.251	2,372	10.442	595.372	149.438	.688656
	65+	11-70	2	43.4	.002	1,215	.087	2.430	.005	.002430
Mixed woods	0-34	70+	5	47.9	.006	1,951	.287	11.706	.070	.014047
	35-64	70+	66	50.3	.076	1,775	3.823	134.900	10.252	.155339
	65+	70+	6	30.8	.007	3,092	.216	21.644	.152	.025251
Hardwoods	0-34	11-70	2	24.9	.002	493	.050	.986	.001972	.000986
	35-64	11-70	94	22.2	.109	1,806	2.420	196.854	21.457	.228267
	65+	11-70	8	2.6	.009	3,208	.023	28.872	.260	.032481
Hardwoods	0-34	70+	2	29.3	.002	180	.059	.360	.000720	.000360
	35-64	70+	20	19.8	.023	1,006	.455	23.138	.532174	.026609
	65+	70+	6	13.9	.07	711	,097	4.977	.0348	.005806
Total			865	--	1.000	--	45.53	--	--	2.257746

bol, this applies to the mean value previously calculated to be 44.8 cubic feet per acre. The error for the property as a whole is obtained by multiplying 2.125 by area, which for these data is 109,119 cubic feet. Expressed in percent, this error is 4.7 (e.g., 2.125 is 4.7 percent of 44.8).

For example 2, refer to table 7. Here a commonly used procedure is shown in detail. Column 7 lists the product of proportion and variance; these entries are then multiplied by the respective proportions to obtain $P_i^2 S_i^2$ as column 8 entries. Next, division by number of plots provides the entries of column 9 which are summed to give 2.25... . The square root of this sum is 1.503, which is the standard error of the mean used to estimate the sampling error. It is 3.3 percent of $\overline{X} = 45.53$. The corresponding sampling error for the region is 22.545 million cubic feet (3.3 percent of 682,950,000 cubic feet).

Interpretation of Sampling Error

The sampling error is a measure of the variation from one sample to another, but it cannot detect bias. If the same timber estimator repeatedly cruised the same forest and estimated total volume for each cruise, it is unlikely that any two estimates would be identical. We would, however, expect them to vary within a relatively small range. It is this variation that the sampling error measures.

If plots or strips were laid out with an improperly graduated tape, his estimate of total volume would be biased and the sampling error would not detect it. The sampling errors that have been calculated, and the variances used to obtain them, generally do not reflect results of bias, or other nonsampling errors. In the absence of such errors, variation in means or totals due to sampling follows the normal distribution. Thus, it becomes possible to make definite probability statements about the mean of all possible estimates in relation to the particular calculated mean and its sampling error. In example 1, above, the mean was 44.8 cubic feet with a sampling error of 2.1 cubic feet. It is conventional to symbolize these data as 44.8 ± 2.1 cubic feet. If all the associated assumptions are true, the chances are 0.68... (approximately 68 percent) that the mean of all possible estimates lies in the interval 42.7 (44.8 - 2.1) to 46.9 (44.8 + 2.1). Increasing the size of this interval increases the corresponding probability and vice versa.

Extension of these concepts to the results of the growth study is obvious. Calculation of the sampling error

makes use of all study plots in each class and the variance of that class. If there are sampling errors in the estimated areas by classes, these errors too affect the precision of estimated growth. There would be such sampling errors when points are classified on photographs or when areas are determined by the strips or line plots of conventional ground cruising. When photo coverage is complete and all the area is delineated, however, there is no sampling error of class area, although there may be a mistake.

Thus it is seen that "...the sampling error is... the amount by which an estimate ... is expected to deviate from the average of all such estimates...".[9]

The sampling error is useful to the practical forest manager because it provides him with an index of the confidence appropriate to the corresponding average. But he must also realize that bias may impair the confidence. An average of 40 with a sampling error of 40 is obviously unreliable. Reducing the sampling error to 4 increases the associated confidence but does not rule out possible bias. Sources of bias are innumerable. In this study we sought to eliminate or reduce bias as much as possible. But it is not likely that we completely eliminated bias.

Discussion of Results

Mean or total growth and its error may be estimated by the methods described for any forest property in the spruce-fir-region when areas or proportions by the classes used in this study are known. However, the representativeness of these data has not been analyzed. To be able to pool data from two or more companies we must assume that there were equal averages by classes. When all plots have been remeasured once, this hypothesis will be tested by formal analysis.

Strictly speaking, these data are also limited to the period actually studied. This would of course defeat the purpose for which the study was made. To use these data for other periods requires the assumption that means by classes

[9]Hendricks, Walter A. The mathematical theory of sampling. 364 pp. Scarecrow Press, New Brunswick, N.J., 1956.

do not change with time. Repeated remeasurement will provide data for testing the assumption that class means do not change. Losses due to birch dieback and the beech scale-nectria may have resulted in abnormal mortality for birch and beech thus reducing net growth. Or, on the other hand, earlier losses may have so reduced density that growth of other species was greater than it should have been. It is factors such as these that require us to be careful in applying growth averages from one period to a different one.

FACTORS AFFECTING NET GROWTH

In table 4, the components of net growth were presented and passed over for later discussion. Insofar as these data are representative, they suggest (1) that softwoods contribute more to growth proportionately than hardwoods and (2) that spruce-fir-hemlock and beech-birch-maple account for most of the growth of softwoods and hardwoods respectively. It should be noted that these various species groups are not independent; the heavier the stocking is to softwoods, the less room there is for hardwoods, and vice versa. Similar considerations apply to any mutually exclusive species groupings. In terms of sampling errors by species groups, variance tends to be inflated as there is greater variation in total softwoods, for example, than in the total of all species.

Influence of Mortality

Another aspect of these data is the distribution of net growth among accretion, ingrowth, and mortality. In a virgin forest there is no net growth, except for limited periods and areas, as mortality tends to equal accretion plus ingrowth. In a well managed forest, on the other hand, accretion plus ingrowth will greatly exceed mortality as weakened and suppressed trees are harvested before their death to provide more growing space for the better trees. Thus as the quality of forest management improves, losses due to mortality should become trivial. For these plots as a whole, mortality expressed as a percentage of weighted average net growth was 16 percent for spruce-fir-hemlock; 18 percent for all softwoods; 123 percent for beech-birch-maple; 180 percent for all hardwoods; and 26 percent for all species.

Influence of Ingrowth

Ingrowth provides a clue to the quality of management a stand has received. It is evident that trees just passing

the threshold of merchantable size may be uneconomic to harvest. It is also clear that without ingrowth there would eventually be no more trees to harvest. Thus good forest management requires ingrowth.

Ingrowth is probably most useful when related to accretion as a percentage. The optimum value of this percentage is so affected by units of measure, limits of merchantability, and goals of management that no universal value is possible. Data from this study show the percentages to have been remarkably consistent. They were 48, 45, 50, 53, and 47 for spruce-fir-hemlock, all softwoods, beech-birch-maple, all hardwoods, and all species respectively. As we gain experience with managed forests, we should study these percentages as a possible guide to the quality of management in relation to specific goals.

Influence of Management

Even without management experience we can see how net growth may be affected by what we do to our forests. No cutting, or cutting at intervals that are too long, results in unharvested mortality which reduces net growth and sacrifices some of the yield from the land. Of course, mortality of trees too small to harvest at a profit, is no direct economic loss. Also cutting that is too heavy, too frequent, or that removes the wrong trees may also reduce net growth, or put too much of it into ingrowth. In harvesting trees from a forest, the manager may select the trees on which he will secure added growth. Proper choice of these trees will maximize net income from the forest which should be his objective.

For estimating growth, it is evident that cutting is likely to affect areas by classes. Thus to avoid bias, class areas must be adjusted as needed. In some instances, cutting may so reduce the residual stand that there will be essentially no growth during the time a new stand is becoming established.

Summary

Average growth rates by classes of forest land have been obtained for this first report of results from the cooperative spruce-fir growth study. Usable averages, reported for all but one of the classes, partially meet the objective of this study. It is now possible to estimate growth and to

calculate its sampling error for a particular forest property in the spruce-fir area of Maine and northern New Hampshire. When all plots have been remeasured some small changes may be expected, but it is not likely that serious error would result from proper use of the averages reported in this paper.

Proper use of the data requires recognition of their limitations and of their representativeness. The study was designed to obtain average growth rates for the common classes of forest land in the area sampled. The goal was to enable landowners to make reliable estimates of growth on various forest properties. Areas by classes are required, as well as the average rates obtained from this study; these areas should, of course, reflect changes due to cutting or other factors, to give an accurate picture of the period of estimation. Good results may be expected for such properties in the general area sampled provided that the averages by classes do not change with time and that the classes are mainly those well represented in this study. For example, reliable statistics cannot be obtained from two plots. In general, however, use of these data should give valid estimates of growth, and its error, for properties in the spruce-fir region of Maine and northern New Hampshire.

Averages from this study are considerably greater than one-tenth of a cord per acre per year. They are also somewhat greater than had commonly been supposed but no more so than had been indicated by other studies, such as the plots that have been remeasured in the areas cut to study effects of the expected attack by spruce budworm. Results of this study may have led to some reconsideration of company plans and policies. The timber resource in this spruce-fir area now appears more attractive for continued operation than had been recognized. Perhaps there is room to expand the wood-using industries in this area. Furthermore, with at least one class already averaging a cord per acre per year of gross growth, it becomes more attractive to do a better job of forest management and perhaps attain a net growth of a cord per acre per year.

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About the authors...

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